NO COMPTON REFLECTION IN A CHANDRA/RXTE OBSERVATION OF Mkn 509: IMPLICATIONS FOR THE FE-K LINE EMISSION FROM ACCRETING X-RAY SOURCES

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ABSTRACT

We report the results of simultaneous *Chandra* and *RXTE* observations of the Seyfert 1 galaxy Mkn 509. We deconvolve the broad and narrow Fe-K emission-line components, for which we measure rest-frame equivalent widths of 119 ± 18 eV and 57 ± 13 eV respectively. The broad line has a FWHM of $57,600^{+14,400}_{-21,000}$ km/s and the narrow line is unresolved, with an upper limit on the FWHM of $4,940$ km/s. Both components must originate in cool matter since we measure rest-frame center energies of $6.36^{+0.13}_{-0.12}$ keV and 6.42 ± 0.01 keV for the broad and narrow line respectively. This rules out He-like and H-like Fe for the origin of both the broad and narrow lines. If, as is widely accepted, the broad Fe-K line originates in Thomson-thick matter (such as an accretion disk), then one expects to observe spectral curvature above ~ 10 keV, (commensurate with the observed broad line), characteristic of the Compton-reflection continuum. However, our data sets very stringent limits on deviations of the observed continuum from a power law. Light travel-time delays cannot be invoked to explain anomalies in the relative strengths of the broad Fe-K line and Compton-reflection continuum since they are supposed to originate in the same physical location. We are forced to conclude that *both* the broad and narrow Fe-K lines had to originate in Thomson-thin matter during our observation. This result, for a single observation of just one source, means that our understanding of Fe-K line emission and Compton reflection from accreting X-ray sources *in general* needs to be re-examined. For example, if an irradiated accretion disk existed in Mkn 509 at the time of the observations, the lack of spectral curvature above ~ 10 keV suggests two possibilities. Either the disk was Thomson-thick and highly ionized, having negligible Fe-K line emission and photoelectric absorption, or the disk was Thomson-thin, producing some

or all of the broad Fe-K line emission. In the former case the broad Fe-K line had to have been produced in a Thomson-thin region elsewhere. In both cases the predicted spectral curvature above ~ 10 keV is negligible. An additional implication of our results is that any putative obscuring torus in the system, required by unification models of active galaxies, must also be Thomson-thin. The same applies to the optical broad line region (BLR) if it has a substantial covering factor.

Subject headings: accretion disks – galaxies: active – galaxies: individual: Mkn 509 – X-rays: galaxies – X-rays: binaries

1. INTRODUCTION

It is now widely accepted that the hardening above $\sim$ 10 keV commonly observed in the X-ray spectra of accretion-driven sources (active galactic nuclei (AGN), and X-ray binary systems) is due to Compton reflection of the primary X-ray continuum in a Thomson-thick accretion disk (e.g. Guilbert & Rees, 1988; Lightman & White 1998; Pounds *et al.* 1990; Zdziarski, Lubiński, & Smith 1999). This basic picture is very attractive because it produces Fe-K fluorescence (e.g. George & Fabian 1991) so that the model can simultaneously account for the Compton-reflection continuum (CR), and the broad Fe-K lines in AGN (Nandra *et al.* 1997; Fabian *et al.* 2000; Yaqoob *et al.* 2002). In fact, from basic physics, if one observes a certain amount of Fe-K line emission, one should observe a corresponding CR whose amplitude relative to the direct X-ray continuum is commensurate with the Fe-K line emission. The precise relation between the Fe-K line and CR depends on physical parameters (Fe abundance, ionization state etc.) but the relationship is fixed by physics since the line and CR photons originate in the same physical location.

In this paper we report the results of a simultaneous *Chandra / RXTE* observation of Mkn 509 in which the CR was absent, and yet a broad Fe-K line from cool material was present with an equivalent width of 119 ± 18 eV. This result from a single observation of one source is important because it questions the above model, and forces us to re-examine our understanding of the Fe-K line and CR in *all* accreting X-ray sources. The paper is organized as follows. The data are described in §2 and spectral fitting results given in §3. In §4 we discuss possible explanations for the lack of spectral curvature in the hard X-ray spectrum and show that all of them are problematic. After discussing some results from historical X-ray observations in §5, we are lead to the inference, discussed in §6, that both the broad and narrow Fe-K emission lines in Mkn 509 during our observations must have originated in cool, Thomson-thin matter. Our conclusions are summarized in §7.

2. CHANDRA AND RXTE DATA

Mkn 509 is a bright, variable Seyfert 1 galaxy ($z = 0.034397$, $L_{2-10\ \mathrm{keV}} \sim 2-4 \times 10^{44}$ ergs/s). We observed Mkn 509 with the *Chandra HETGS* on 2001 April 13–14, simultaneously with *RXTE*. The *Chandra* data were reduced in the manner described in Yaqoob *et al.* 2001, except that CALDB version 2.7 was used and the data reprocessed using `ciao 2.1.3`[7]. The *RXTE* PCA data were reduced using methods described in Weaver, Krolik, & Pier (1998), except that we used a later version of the spectral response matrix (V 7.10) and background model ('L7_240_FAINT'). Only data from layer 1 and from PCU 2, 3 and 4 were used (PCU0 has had technical problems in the later part of the mission and PCU1 was off). Note that cross-calibration studies show that in the 2–10 keV band PCA fluxes are systematically at least 20% higher than *ASCA* whereas *ASCA* and *BeppoSAX* fluxes agree to a few percent [8].

We examined lightcurves from the *RXTE* observation (beginning 2001 April 13 UT 04 50:07, with a total duration of 121 ks), and the *Chandra* observation (beginning at UT 2001 April 13 UT 08 01:31, with a total duration of ~ 59 ks). Only the summed, negative and positive first order *Chandra* grating spectra were used in our analysis. The mean *Chandra* total HEG and MEG count rates were 0.2134 ± 0.0015 and 0.4813 ± 0.0022 cts/s respectively. For the PCA, the mean, background-subtracted 2–10 keV and 2–20 keV count rates were 4.71 ± 0.01 and 5.77 ± 0.01 ct/s respectively. The source flux showed little variability over the entire duration of the campaign. For example, for HEG plus MEG lightcurves binned at 1024 s, the excess variance above the expectation for Poisson noise (e.g. see Turner *et al.* 1999) was $(-0.8 \pm 3.7) \times 10^{-4}$, consistent with zero. HEG, MEG

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[7] http://asc.harvard.edu/ciao2.1/documents_threads.html

[8] ASCA GOF calibration memo at http://heasarc.gsfc.nasa.gov/docs/asca/calibration/3c273_results.html

and PCA spectra were therefore extracted over the entire on-time for each instrument, combining the PCA data for the three PCUs. This resulted in net exposure times of 57,950 s for HEG and MEG, and 80,624 s for the PCA.

3. SPECTRAL FITTING RESULTS

Whenever the *Chandra* data were fitted without the PCA data, we were able to use the C-statistic and over-sample the spectral resolution of the grating data. However, whenever the *Chandra* data were fitted together with the PCA, the grating data had to be binned in order to use the χ^2 statistic. To this end, the HEG and MEG spectra were binned with a constant wavelength width of 0.02$\AA$ and 0.04$\AA$ respectively. This resulted in spectra with at least 20 counts per bin in the energy ranges 1.3–7.2 keV and 0.64–6.9 keV for HEG and MEG respectively. Therefore, in order to use the χ^2 statistic for spectral fitting, we ignored data above 6.9 keV in both HEG and MEG. Since we will not be concerned with the soft X-ray spectra in this paper, only HEG and MEG data in the 2–6.9 keV band were utilized. Note that at 6.4 keV, the FWHM spectral resolution of the HEG and MEG is 39.6 eV (0.012$\AA$, $\sim 1,860$ km/s) and 76.0 eV (0.023$\AA$, $\sim 3,560$ km/s) respectively. The PCA spectra were used only up to 19 keV, this upper limit determined by the signal-to-noise and background-subtraction systematics. In the remainder of the paper, unless otherwise stated, we shall give model parameters referred to the rest frame of *Mkn 509*, and statistical errors (as well as lower and upper limits) will be given for 90% confidence for one interesting parameter.

Fig. 1 shows the ratio of the HEG data to a simple power-law model fitted over the 2–5 keV band and then extrapolated to higher energies. Also shown in Fig. 1 is the ratio of 3–19 keV PCA data to a simple power law model fitted over the 3–4 keV and 8–19 keV bands. It can be seen that the HEG clearly reveals a narrow Fe-K emission-line component,

centered at ~ 6.4 keV, extending over ~ 0.2 keV in energy. This line is also detected in the MEG, but at that energy the effective area, spectral resolution, and signal-to-noise are substantially worse than the HEG. Fitting the HEG data only, with a power-law plus Gaussian emission line gave an upper limit of $\sigma < 15$ eV (or 4,940 km/s FWHM) for the narrow line. The intensity and energy of the line were allowed to float in the spectral fit but better constraints on these parameters will be derived from joint *Chandra* and *RXTE* spectral fits, described below. Since the narrow line is not resolved, its width was fixed at $\sigma = 1$ eV in all subsequent spectral fitting. In contrast to *HETGS*, Fig. 1 shows that the PCA detects a much broader Fe-K line, with a base extending over ~ 3 keV, nearly three times the FWHM of the PCA energy resolution at 6 keV. Moreover, Fig. 1 shows that there is no complexity in the continuum above ~ 10 keV. In fact, a power law fitted to the HEG and MEG data, extrapolated up to 19 keV gives an excellent fit to the PCA data above 8 keV, after fitting only for the cross-instrument normalization factor.

Full spectral fitting of the HEG, MEG, and PCA data with a power law, two Gaussians (line energies, intensities, and the broad-line width free), plus a Compton-reflection continuum (CR) from neutral matter (PEXRAV in XSPEC, with the disk inclination angle initially fixed at 30°), shows that the covering factor, R, is consistent with zero. Here R is the fraction of 2π steradians subtended by the slab at the X-ray source. Fig. 2 shows confidence contours of R versus the width of the broad Fe-K line. This shows that the upper limit on R is very small: $R < 0.11$ at 99% confidence for two parameters. A larger disk inclination does of course allow a larger upper limit on R (but still gives a best-fit of zero). However, then the predicted equivalent width (EW) of the broad line diminishes, but as we shall see below, the EW is already severely under-predicted even for an inclination angle of zero. We note that Fig. 2 also shows that *RXTE* actually resolves the broad Fe-K line (in this fit, $\sigma > 0.15$ keV, or FWHM $> 16,630$ km/s, at 99% confidence, two parameters).

Having established that the data do not require any CR, we proceeded to find the best-fitting parameters and constraints on the Fe-K lines by repeating the above fits with only a simple power law plus two Gaussians. Fig. 3 shows the best-fitting model, along with the HEG, MEG, and PCA ratios of data to this best-fitting model. An excellent fit was obtained, with $\chi^2 = 330.8$ (355 degrees of freedom). We denote the center energy, Gaussian width, and emission-line intensity by E_c, σ, and I respectively. The results are given in Table 1. We obtained, for the narrow line (σ fixed at 1 eV): $E_c = 6.42 \pm 0.01$ keV, $EW = 57 \pm 13$ eV, and $I = 3.5 \pm 0.8 \times 10^{-5}$ photons cm^{-2} s^{-1}. For the broad line, we obtained: $E_c = 6.36^{+0.13}_{-0.12}$ keV, $EW = 119 \pm 18$ eV, $\sigma = 0.52^{+0.19}_{-0.13}$ keV (FWHM $= 57,600^{+14,400}_{-21,000}$ km/s), and $I = 7.6 \pm 1.1 \times 10^{-5}$ photons cm^{-2} s^{-1}. We obtained a 2–10 keV flux of 5.1×10^{-11} ergs cm^{-2} s^{-1} (observed frame, using the average best-fitting HEG and MEG normalization), which is about the historical average for Mkn 509 (e.g. Turner & Pounds 1989; Weaver, Gelbord, & Yaqoob 2001). This corresponds to a source-frame 2–10 keV luminosity of 2.7×10^{44} ergs s^{-1} ($H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0$). For the measured values of Γ and equivalent width of the broad Fe-K line (see Table 1), even the 99%, two-parameter upper limit on the amplitude of the CR is too small by a factor of *seven* compared to that expected from the most basic version of the standard model. In that model the broad Fe-K line and CR originate in a neutral, solar abundance, Thomson-thick reflector subtending 2π solid angle at the power-law X-ray continuum source (e.g. see George & Fabian 1991). Modifications to the basic model, as well as possible alternatives for explaining the observational results, will be discussed in §4 and §6.

The inset in Fig. 3 shows confidence contours for the intensities of the narrow and broad Fe-K lines. Clearly, *Chandra*/ and *RXTE* together deconvolve the narrow and broad Fe-K line components. The center energies of both lines indicate an origin in cool material, certainly ruling out emission from He-like or H-like Fe. It is unlikely that the narrow Fe-K line is really part of a single, broad relativistic disk-line profile: we find that the disk

inclination angle is highly constrained ($< 10^\circ$) and the radial emissivity of the disk must be very flat to increase the weighting from the outer parts of the disk. A detailed discussion of these effects can be found in Yaqoob *et al.* ([illegible]) who found similar results for the Seyfert 1 galaxy NGC 5548.

4. POSSIBLE EXPLANATIONS FOR THE LACK OF SPECTRAL CURVATURE

Whilst light travel-time delays can be invoked to explain anomalies in the amplitude of the Compton-reflection continuum (CR) relative to the direct X-ray continuum, the same cannot be done for anomalies between the relative strengths of the CR and broad Fe-K line. This is because both the CR and broad Fe-K line are supposed to originate in the same physical location. In the remainder of this section we discuss possible explanations of the lack of CR in the 2001 *Chandra / RXTE* observations of Mkn 509.

It is well known that an X-ray power-law continuum plus a CR is sometimes indistinguishable from a simple, but flatter power law, if the data quality is poor. This is certainly not the case with our data: even the 99% confidence, two-parameter statistical errors on Γ (1.67) are ± 0.03. We also quantified limits on any spectral curvature in the data, by fitting a power-law continuum (plus two Gaussians) below 10 keV only. We obtained $\Gamma_{2-10\ \rm keV} = 1.671^{+0.010}_{-0.015}$. This is to be compared with $\Gamma_{2-19\ \rm keV} = 1.674^{+0.008}_{-0.009}$ from §3 (and Table 1). Note that 2 keV refers to the lowest energy *Chandra* data used: PCA data below 3 keV were not used. Thus, the limits on spectral curvature are very tight, and the excellent consistency of the two photon indices also gives us confidence that the PCA background was not over-subtracted (which could reduce the apparent CR).

It is also possible that the *intrinsic* continuum has a high-energy cutoff in the observed

energy band, but the CR compensates, giving an observed continuum which has little curvature. For the power law, double Gaussian and CR spectral fit (§3), we modified the intrinsic continuum by an exponential rollover of the form $\exp(-E/E_0)$, and obtained $E_0 = 112^{+338}_{-60}$ keV. The CR is calculated from the modified continuum in this case. Confidence contours of R versus E_0 are shown in Fig. 2 . The best fit still prefers no CR but, as expected, the upper limit on R is higher ($R = 0.00^{+0.42}_{-0.00}$, 99% confidence, two-parameters). However, it is highly unlikely for an exponential cutoff to exactly compensate for the spectral curvature due to the CR, especially given the tight limits set by the consistency of $\Gamma_{2-10\ \rm keV}$ and $\Gamma_{2-19\ \rm keV}$.

Increasing the Fe abundance is another way of reducing the spectral curvature due to Compton reflection. However, direct spectral fitting to the data, with free Fe abundance in PEXRAV, showed that the 99% confidence, two-parameter *lower limit* on the Fe over-abundance is 95 compared to solar. This is clearly absurd (we would see other consequences of such an over-abundance). Ionization also decreases the relative importance of photoelectric absorption relative to Compton downscattering, reducing the strength of the $\sim 10-30$ keV Compton hump and therefore reducing the apparent value of R. However, the degree of ionization required by the data is very high and the peak energy of the broad line rules it out. Smearing, either due to extreme relativistic effects or Comptonization, could reduce the apparent amplitude of the CR. However, any type of smearing cannot be more than that suffered by the broad Fe-K line. Direct spectral fitting to the data with a smeared CR model (`refsch` in XSPEC) assuming the maximum allowed smearing for a disk around a Schwarzschild black hole again gave $R = 0$ and a 99%, two-parameter upper limit of 0.11.

5. PREVIOUS OBSERVATIONS OF Mkn 509

ASCA observations found evidence for variability in the overall Fe-K line profile in Mkn 509 but could not separate the broad and narrow components (Weaver *et al.* 2001). An *XMM-Newton* observation in 2000 April (Pounds *et al.* 2001) found the source to be in a low state with a 2–10 keV flux of $\sim 10^{-11}$ ergs cm^{-2} s^{-1} ($\sim$ 5 times lower than in our observations). A narrow Fe-K line was found at $\sim$ 6.4 keV, with an intensity entirely consistent with that measured during our *Chandra / RXTE* observation. On the other hand the broad line was lower in intensity by about the same factor as the continuum and was centered at $\sim$ 6.9 keV, indicative of an origin in H-like Fe.

We also checked archival *RXTE* data for Mkn 509 from 1996 and found $R = 0.36 \pm 0.05$ (for a 30° disk inclination angle), and a photon index of $\Gamma = 1.89^{+0.01}_{-0.02}$. For the Fe-K emission line we measured a center energy, width, intensity, and EW of E_c = 6.53 ± 0.05 keV, $\sigma = 0.30^{+0.09}_{-0.10}$ keV (or FWHM = $32,390^{+10,800}_{-9,720}$ km/s), $I = 5.20 \pm 0.06 \times 10^{-5}$ photons cm^{-2} s^{-1}, and EW = 83 ± 8 eV respectively. Note that some of the total Fe-K line may contain a contribution from the narrow line found by *Chandra* and *XMM* but *RXTE* alone cannot deconvolve the broad and narrow components. This analysis shows that the CR in Mkn 509 is variable, and significant spectral curvature was present in the 1996 *RXTE* observation, despite the 2–10 keV flux (5.8×10^{-11} ergs cm^{-2} s^{-1}) being similar to that in the 2001 *Chandra / RXTE* observation.

6. DISCUSSION

These results for Mkn 509 are quite profound. The Compton-reflection continuum (CR) was absent during *Chandra / RXTE* observations in 2001, yet there was substantial broad (FWHM $57,600^{+14,400}_{-21,000}$ km/s) Fe-K line emission from cool Fe. The center energy of a

narrow, unresolved Fe-K line (FWHM $<$ 4,940 km/s) also indicated that it too originated in cool matter. If the broad Fe-K line originated in Thomson-thick matter, where was the CR that *must*, from basic physics, accompany the line? We are forced to conclude that the broad Fe-K line originated in cool, *Thomson-thin* matter. If an accretion disk existed in the system during our observations, and if the disk was irradiated by an X-ray continuum corresponding, at least in spectral shape, to the one we measured, then either most of the disk must have been Thomson-thin, or the disk was Thomson-thick but so heavily ionized that all Fe (and lighter) atoms were completely stripped. In the latter scenario the CR has no curvature from photoelectric absorption and any deviations in the CR compared to the intrinsic continuum are negligible in our energy band (2–19 keV). The fact that Pounds *et al.* (2001) observed a broad, H-like Fe-K line component in Mkn 509 lends support to a high (and by implication, variable) state of ionization of the putative accretion disk. Indeed, when we fitted the 2001 *Chandra / RXTE* data with an ionized disk model in which the CR is determined completely by physics and cannot be artificially reduced (`xion` in XSPEC; see Nayakshin & Kallman 2001), we found a large region in parameter space which yielded negligible Fe-K line emission and continuum curvature. We were able to obtain fits to the data with a completely ionized disk plus two Gaussians for the Fe-K lines which were as good as the fits in which the continuum was only a simple power law. If the disk is completely ionized it cannot of course produce any Fe-K line emission and the observed broad Fe-K emission line must then be made elsewhere, *but still in cool Thomson-thin matter*, so as again not to over-produce spectral curvature due to Compton reflection. This applies to *both the broad and narrow Fe-K lines*. In particular, if the obscuring torus hypothesized to unify type 1 and type 2 AGN exists in Mkn 509 it must be Thomson-thin, or else so ionized that Fe is fully stripped. In the latter case, the *narrow* Fe-K line must be produced elsewhere, such as the BLR (which must itself be Thomson-thin, if it has a substantial covering factor).

For neutral matter with column density N_{23} (in units of 10^{23} cm^{-2}), a covering factor f_c, an Fe abundance relative to solar of $A_{\rm Fe}$, illuminated isotropically by a power-law continuum (with photon index Γ), the predicted equivalent width of the Fe-K line in the Thomson-thin limit is EW $\sim 97 f_c N_{23} A_{\rm Fe}$ eV (e.g. Yaqoob *et al.* 2001). Here we have used the measured value of Γ (see Table 1). A spherical geometry for the line emitter requires a gas distribution that does not intercept the line-of-sight. This is because absorption column densities which are large enough to account for the Fe-K line emission would extinguish the soft X-ray spectrum too much and imprint an Fe-K edge at 7.11 keV, in conflict with the data. We obtained a direct constraint on the line-of-sight column density of a neutral, solar abundance absorber of $N_{23} < 0.033$ (from joint *Chandra* / *RXTE* spectral fitting with the power-law and double Gaussian model, with the addition of an Fe-K edge at 7.11 keV). Similar constraints are obtained from the soft X-ray spectrum (see Mckernan *et al.* 2002).

In a planar geometry, a Thomson-thin matter distribution illuminated isotropically on *both sides* by an X-ray source (either a disk with a central X-ray source close to the disk plane, or a coronal source distributed over the disk), has $f_c \sim 1$. However, we must halve the predicted EW because the continuum from the other side of the disk would also penetrate the Thomson-thin disk. For a Thomson-thick, completely ionized disk, a possible location for the Thomson-thin, line-producing material is a cool atmosphere over the disk. In that case, $f_c \sim 0.5$. Thus, in any of the above scenarios, the observed EW of the broad Fe-K line can be accounted for with solar abundances and $N_{23} \sim 2.5$ This corresponds to a Thomson depth of 0.2, small enough that the amplitude of the reflected X-ray continuum is negligible compared to the direct continuum, and therefore giving negligible spectral curvature to the observed continuum.

Obviously, all of the above scenarios represent a departure from widely-accepted ideas, and each also faces various challenges. Our results should prompt theoretical investigations,

(in particular of time-averaged and time-variable vertical structure of accretion disks), to see if they can be understood in detail. Historical observations of Mkn 509 showing significant variability (for example, the *RXTE* detection of the CR in 1996, and the *XMM-Newton* measurement of a broad H-like Fe-K line by Pounds *et al.* 2001), should provide critical constraints on models.

7. CONCLUSIONS

A simultaneous *Chandra HETGS* and *RXTE* observation of the Seyfert 1 galaxy Mkn 509 deconvolved the narrow (FWHM $< 4,940$ km/s) and broad (FWHM $57,600^{+14,400}_{-21,000}$ km/s) Fe-K emission lines (both centered around ~ 6.4 keV), and found no deviation in the continuum from a power law out to 19 keV. The lack of spectral curvature due to a Compton-reflection continuum (CR) then fails to account for the broad Fe-K line in terms of standard, Thomson-thick accretion-disk models. Such a failure of the standard model for a single source implies that our understanding of the Fe-K line and CR in accreting X-ray sources in general needs to be re-examined. An inescapable conclusion is that both the broad and narrow Fe-K lines must come from cool, Thomson-thin matter, at least during the 2001 *Chandra* / *RXTE* observations.

There are other implications which follow from our results. One is that the lack of correlation between the broad Fe-K line and the CR in some AGN, which appeared to be troublesome in the context of standard disk models (e.g. Chiang *et al.* 2000; Ballantyne, Ross, & Fabian 2001), should not now be surprising since some of the broad Fe-K line may come from Thomson-thin matter. Another implication is that models accounting for the claimed anti-correlation between the effective covering factor of the CR and the power-law index of the intrinsic X-ray continuum (e.g. Zdziarski *et al.* 1999) must also be able to account for spectra which show negligible spectral curvature. A further corollary of our

findings is that the practice of performing spectral fits to data with the strength of the Fe-K line and CR tied together on the basis of the standard model is not justified and may lead to erroneous conclusions.

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Table 1. HEG, MEG, PCA Joint Spectral Fitting Results for Mkn 509

Parameter	Value
χ^2 (degrees of freedom)	330.8 (355)
Photon Index (Γ)	$1.674^{+0.008}_{-0.009}$
2–10 keV flux	5.1×10^{-11} ergs cm^{-2} s^{-1}
Broad Fe-K Line:	
Center Energy	$6.36^{+0.13}_{-0.12}$ keV
Width (σ, FWHM)	$0.52^{+0.19}_{-0.13}$ keV, $57,600^{+14,400}_{-21,000}$ km/s
Intensity	$7.6^{+1.1}_{-1.1}$ $\times 10^{-5}$ photons cm^{-2} s^{-1}
Equivalent Width (EW)	119^{+18}_{-18} eV
Narrow Fe-K Line:	(σ fixed at 1 eV)
Center Energy	$6.42^{+0.01}_{-0.01}$ keV
Intensity	$3.5^{+0.8}_{-0.8}$ $\times 10^{-5}$ photons cm^{-2} s^{-1}
Equivalent Width (EW)	57^{+13}_{-13} eV
Velocity FWHM Upper Limit	4,940 km/s

Note. — Results of fitting the 2.0–6.9 keV *Chandra* HEG, MEG, and 3–19 keV *RXTE* PCA Mkn 509 data with a simple power law and two Gaussians (the latter modeling the complex Fe-K line emission). All line parameter values are referred to the rest frame of Mkn 509 (z = 0.034397). Statistical errors are 90% confidence for one interesting parameter ($\Delta\chi^2 = 2.706$). The 2–10 keV flux is from average HEG and MEG normalization, observed frame.

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Figure Captions

Figure 1

The ratio of *Chandra* HEG and *RXTE* PCA data to a power law fitted in the 2–5 keV band (HEG) and in the 3–4, 8–19 keV bands (PCA) for Mkn 509 ($z = 0.034397$). The HEG bin width is 0.02Å. The energy scale corresponds to the *observed* frame. The HEG shows a sharp, unresolved, narrow Fe-K line at ~ 6.4 keV, source frame. The PCA data show a broad, resolved, composite Fe-K line profile extending over a few keV. The spectral curvature in the continuum, characteristic of Compton reflection in neutral, Thomson-thick matter, is absent. The observed continuum is consistent with a single power law.

Figure 2

Confidence contours from a joint HEG, MEG and PCA spectral fit with a power law, narrow and broad Gaussian Fe-K emission lines, and a Compton-reflection continuum (see text), showing the effective covering factor of the latter, R, versus the broad Fe-K line Gaussian width. R is a fraction of 2π steradians solid angle subtended by the reflector at the X-ray source. The 68%, 90% and 99% confidence contours show that *RXTE* resolves the broad line and that no Compton reflection is detected, with a very small upper limit on the covering factor, R. If the power-law continuum is modified by an exponential high-energy roll-over of the form $\exp(-E/E_0)$, the upper limit on R is larger (68%, 90%, and 99% confidence contours of R versus E_0 are shown in the inset). However, it is highly unlikely for the amount of rollover to exactly compensate for the curvature due to Compton reflection, giving a negligible change in power-law slope with energy ($\Gamma_{2-10\ \mathrm{keV}} = 1.674^{+0.010}_{-0.015}$, and $\Gamma_{2-19\ \mathrm{keV}} = 1.674^{+0.008}_{-0.009}$). All quantities shown in this figure refer to the source frame.

Figure 3

Best-fitting power-law ($\Gamma = 1.674$[illegible]) and dual Gaussian model, simultaneously using HEG (crosses), MEG (open circles), and PCA data (solid) for Mkn 509. The bottom panel shows the ratio of data to the best-fitting model. In the source frame, the best-fitting narrow Fe-K line parameters are $E_c = 6.42 \pm 0.01$ keV, $EW = 57 \pm 13$ eV (width, σ, fixed at 1 eV) and the best-fitting broad Fe-K line parameters are $E_c = 6.36^{+0.13}_{-0.12}$ keV, $EW = 119 \pm 18$ eV, $\sigma = 0.52^{+0.19}_{-0.13}$ keV (FWHM $57,600^{+14,400}_{-21,000}$ km/s). The inset shows the 68%, 90%, and 99% confidence contours of the intensities of the narrow and broad Fe-K lines (in units of photons cm^{-2} s^{-1}), which are deconvolved (see text). The HEG and MEG bin widths are $0.04\AA$ and $0.08\AA$ respectively (although half these values were used for spectral fitting). The energy scale corresponds to the *observed* frame.

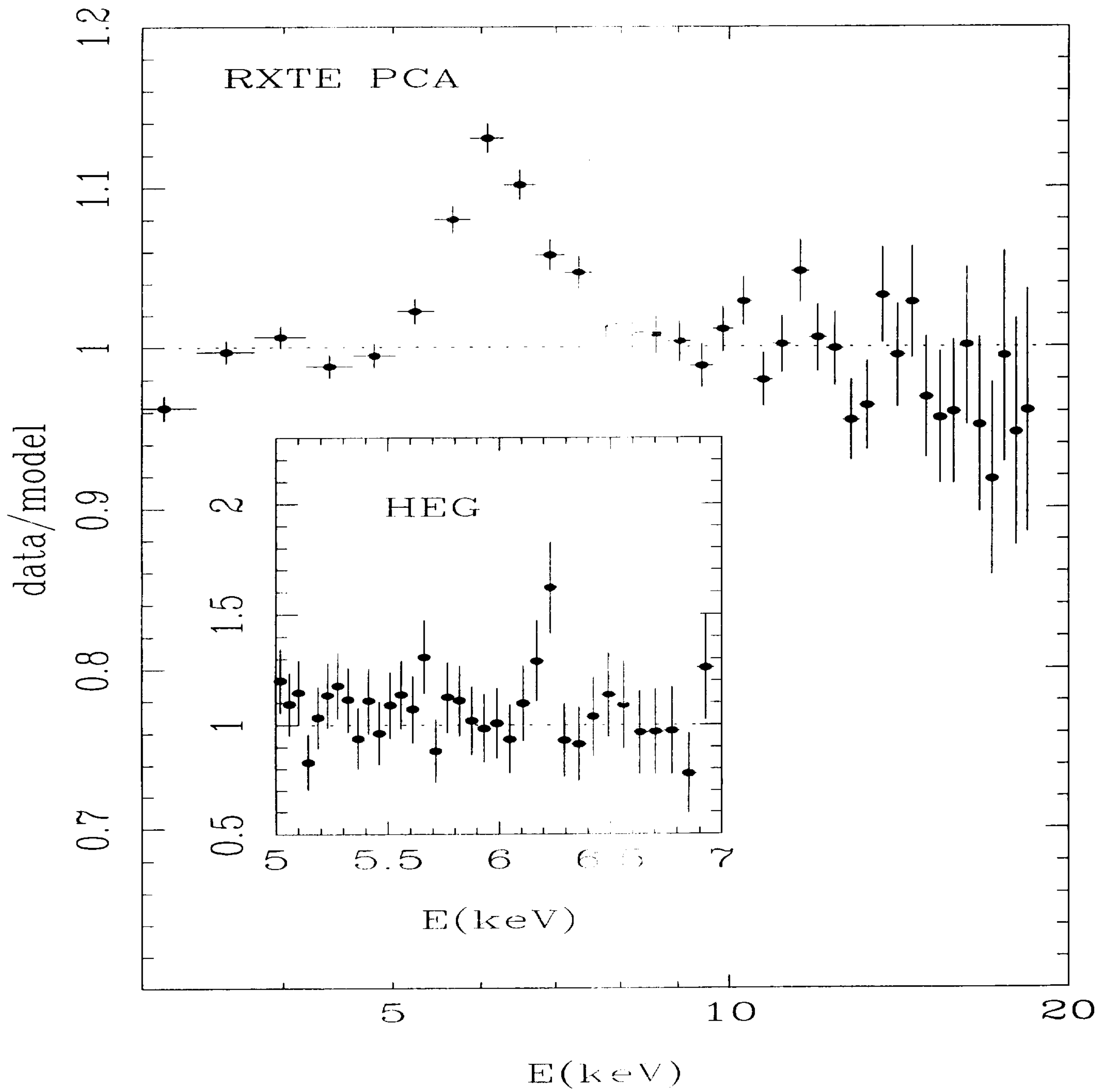

RXTE PCA
HEG
data/model
E(keV)
E(keV)
1.2
1.1
1
0.9
0.8
0.7
5
10
20
2
1.5
0.5
5.5
6
6.5
7

Fig. 1.—

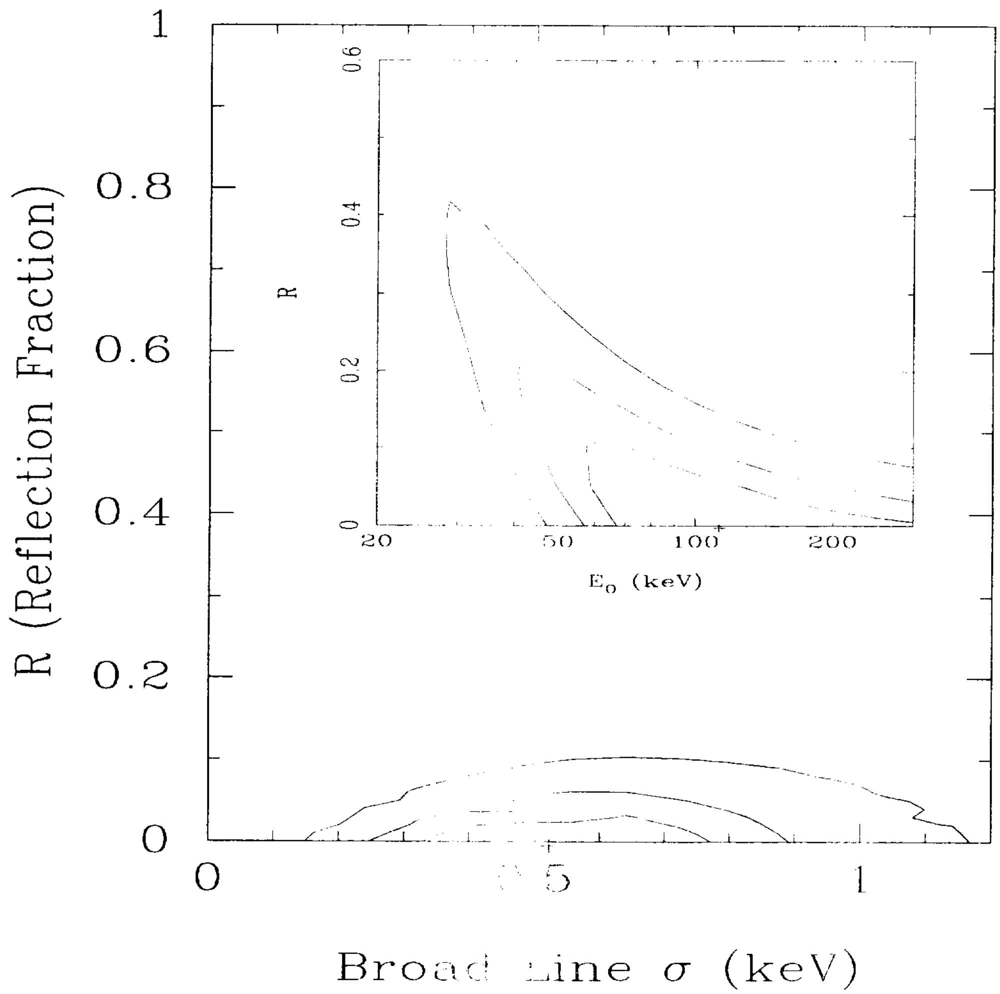
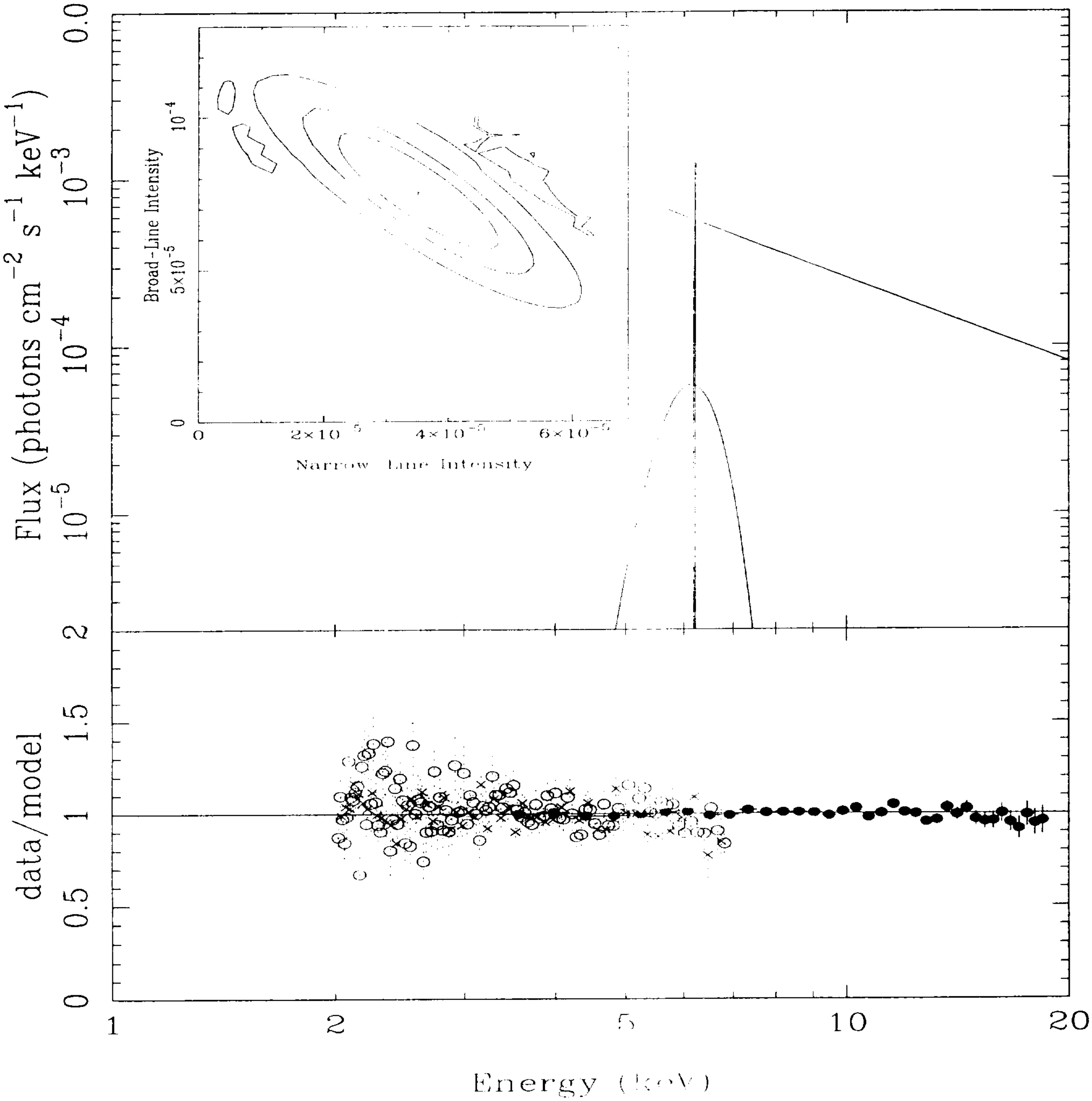

R (Reflection Fraction)
Broad Line σ (keV)
0
0.2
0.4
0.6
0.8
1
0
1
R
E_0 (keV)
20
50
100
200
0.2
0.4
0.6

Fig. 2.—



Flux (photons cm^{-2} s^{-1} keV^{-1})
0.01
10^{-3}
10^{-4}
10^{-5}
2
1.5
1
0.5
0
data/model
1
2
5
10
20
Energy (keV)
Broad-Line Intensity
10^{-4}
5×10^{-5}
0
0
2×10^{-5}
4×10^{-5}
6×10^{-5}
Narrow Line Intensity

Fig. 3.—